Progress Towards Realistic Geometry and Global Implementations of the Summit Gyrokinetic Framework*

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Abstract

The Summit Framework is a gyrokinetic particle-in-cell turbulence simulation environment that incorporates several algorithmic advances including the delta-f solution of the toroidal gyrokinetic Vlasov equation for the ion dynamics, field-aligned "quasi-ballooning" numerical representation and a flux tube simulation domain[1,2]. The ions have equilibrium temperature and density gradients. Self-generated and external flows are included. The Summit Framework, written in Fortran 90, provides a unified object-based environment for sharing common components in a m assively parallel setting. Work is underway though the Summit Framework to include kinetic electron models and electromagnetic effects[3,4], realistic magnetic geometry using quasi-ballooning coordinates[2] and global effects under one software environment. This will allow the scientist to choose the physics components (and associated numerical advantages and disadvantages) most appropriate for the given problem at hand. This presentation will report on progress towards realistic geometry and global implementations of the Summit Framework building from the PG3EQ code[1]. Work on general geometry starts with the base code that is electrostatic and the electron response is taken to be adiabatic, with a zero response to the flux surface averaged potential. Serial and parallel versions of the set-up routines based on an interface to EFIT data necessary for realistic equilibria are being retrofitted into the Summit Framework. In addition, ways of covering more of the plasma minor radius within the context of the quasi-ballooning representation are being investigated. Procedures and tests will be reported as available.

[1] A. M. Dimits, T. J. Williams, J. A. Byers, B. I. Cohen, "Scalings of ion-temperature-gradient-driven anomalous transport in tokamaks." Phys. Rev. letts. **77**, 71 (1996).
[2] http://www.nersc.gov/scidac/summit/
[3] Y. Chen, S. Parker, "Gyrokinetic turbulence simulations with kinetic electrons", Phys. Plasmas **8**, 2095 (2001)
[4] Bruce I. Cohen, Andris M. Dimits, William M. Nevins, Yang Chen, Scott Parker, "Kinetic electron closures for electromagnetic simulation of drift and shear-Alfven waves. I. ", Phys. Plasmas **9**, 251-262 (2002).

Outline

- Motivation
- Summit Framework Overview
- Realistic Geometry Implementation
- Summary and Future Directions

Motivation

• Realistic geometry capability is needed in the Summit Framework to facilitate model/experiment comparisons

• This capability has been partially provided in the PG3EQ code ("reliable" serial version; "in progress" massively parallel version)

• This work attempts at completing the implementation of realistic geometry in the the massively parallel Summit Framework through the PG3EQ module

Summit Framework Overview

• Summit is an open-source framework for both local and global massively parallel gyrokinetic turbulence simulations

• Work is underway through Summit to include kinetic electron models with electromagnetic fluctuations, realistic geometry using quasi-ballooning coordinates, and global effects

• The Summit Framework, written in Fortran 90, provides a unified object-based environment for sharing common components in a massively parallel setting

See Poster 1D09 by S. E. Parker, Y. Chen, B. I. Cohen, A. M. Dimits, W. M. Nevins, D. Shumaker, J. N. Leboeuf, V. K. Decyk, “Overview of the Summit Framework: Open-Source Software for Large-Scale Gyrokinetic Turbulence Simulation”

Realistic Geometry Implementation

- Builds from the PG3EQ module [Dimits et al. PRL **77**, 71, 1996] in Summit

- Starts with a base PG3EQ code that is electrostatic and with adiabatic electrons

- So far uses INTERFACE code of A. Brizard and J. Kirkpatrick [LBL,~1992-4] to read needed equilibrium data from EFIT and ENERGYand extract/define equilibrium profiles and magnetic flux coordinates for PG3EQ module

PG3EQ Module

- Incorporates several algorithmic advances:
  - δf solution of the nonlinear toroidal gyrokinetic Vlasov equation for the ion dynamics with equilibrium density and temperature gradients
  - Field-aligned "quasi-ballooning" numerical representation
  - Flux tube simulation domain which spans one or more poloidal circuits in the parallel direction

- Adiabatic electrons, with a zero response to the flux averaged potential

PG3EQ Module: Quasiballooning coordinates and representation

- Quasiballooning coordinates

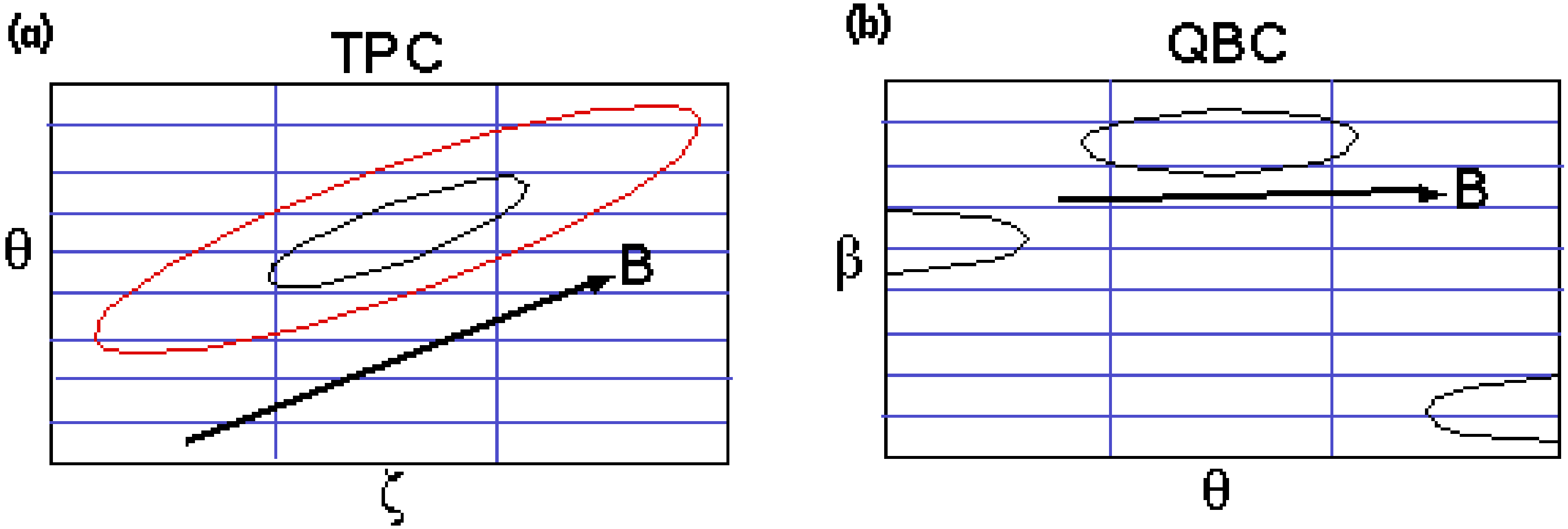
  - nearly field aligned
  - grid lines continue exactly into grid lines across || boundary
  - affects || derivative
    || periodicity
    $\perp$ periodicity

- $\nabla_{\|} = \frac{1}{q_0 R}[\frac{\partial}{\partial\theta} + (q - \hat{q})\frac{\partial}{\partial\beta}]$

- Allows any q(r) profile

PG3EQ Module: Quasiballooning coordinates

• Quasiballoooning coordinates (QBC) versus Toroidal-poloidal coordinates (TPC)



•TPC: The larger ellipse is the smallest plasma structure than can be resolved with the grid resolution

• QBC: by (almost)aligning a coordinate with the magnetic field, the smaller plasma structure is resolved with the same number of grid points;ordinary periodicity in quasi-poloidal angle β

PG3EQ Module:General Cross Section Spatial Representation

• Extension of quasiballooning representation to non-circular cross section and arbitrary aspect ratio equilibria carried out within the framework of simulations that use a thin flux tube or toroidal annulus geometry

• Resulting representation takes into account variations in flux tube shape, magnetic field strength, normal and geodesic curvatures, gyroradii, with poloidal angle

• Formalism based on general set of flux coordinates (ρ,θ,ζ) where ρ is a generalized radial coordinate which labels the flux surface and is a monotonic function of poloidal flux ψ, θ is a generalized poloidal angle, and ζ is the true toroidal angle. [Hua et al., Phys Fluids **B4**, 3216 (1992)]

PG3EQ Module:General Cross Section Spatial Representation

- Quasiballooning coordinates:

radial	r	$\longrightarrow$	r	radial
poloidal	θ	$\longrightarrow$	θ	quasiparallel
toroidal	ζ	$\longrightarrow$	β	perpendicular

$$\beta \equiv \zeta - \int_{\theta_0}^{\theta} d\theta \hat{q}(\rho,\theta) \qquad \hat{q}(\rho,\theta) = q(\rho,\theta) - \Delta\rho$$

- $q(\rho,\theta) \equiv h_\theta \dfrac{B_t}{RB_p}; dl_\theta = h_\theta d_\theta$

- $\Delta(\rho)$ = small offset to permit seamless parallel periodicity

[Circular cross section: $\beta = \zeta - \hat{q}(r)\theta$]

PG3EQ Module:General Cross Section Spatial Representation

- Particle push uses ρ, θ, β_0 where

$$\beta_0 \equiv \zeta - \int_{\theta_0}^{\theta} d\theta q(\rho_0, \theta)$$

- Simplest choice for interpolation and deposition

- For thin annulus or flux tube:

$$q(\rho,\theta) \cong q_0(\theta) + \rho q_\rho(\theta)$$

$$\beta \cong \zeta - \int_{\theta_0}^{\theta} d\theta q_0(\theta) - \rho \int_{\theta_0}^{\theta} d\theta q_\rho(\theta)$$

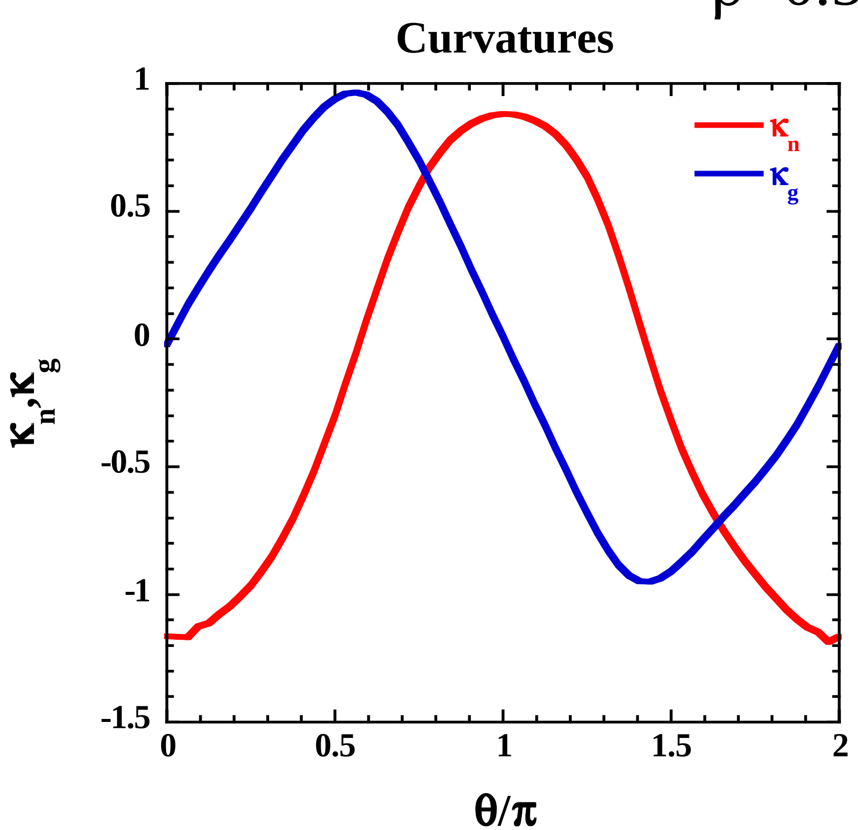
$$\beta_0 \cong \zeta - \int_{\theta_0}^{\theta} d\theta q_0(\theta)$$

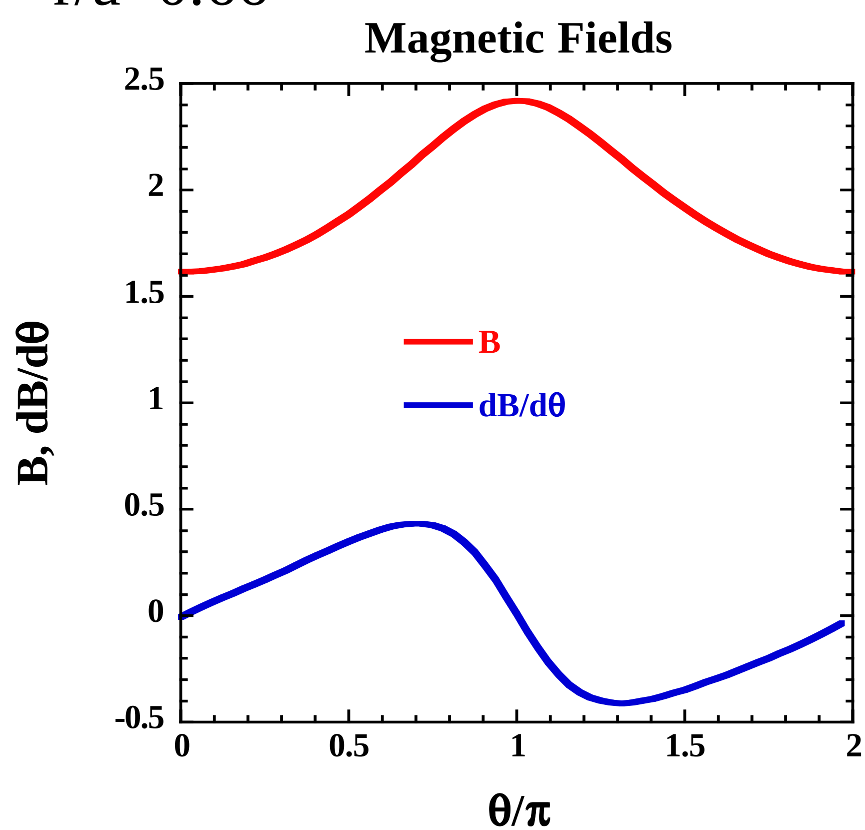
INTERFACE Code

- Needed equilibrium quantities and coordinates for general geometry extension defined by INTERFACE code of Brizard and co-workers from EFIT and ENERGY data

- Typical INTERFACE Output Data: DIIID Shot # 81499 ,4000ms

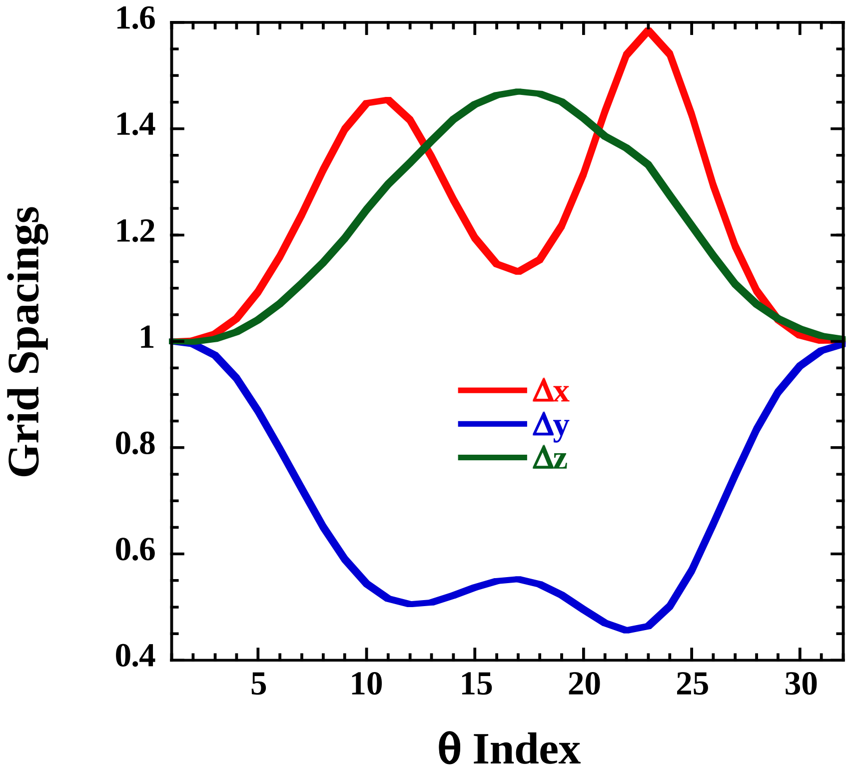
ρ=0.5   r/a=0.66

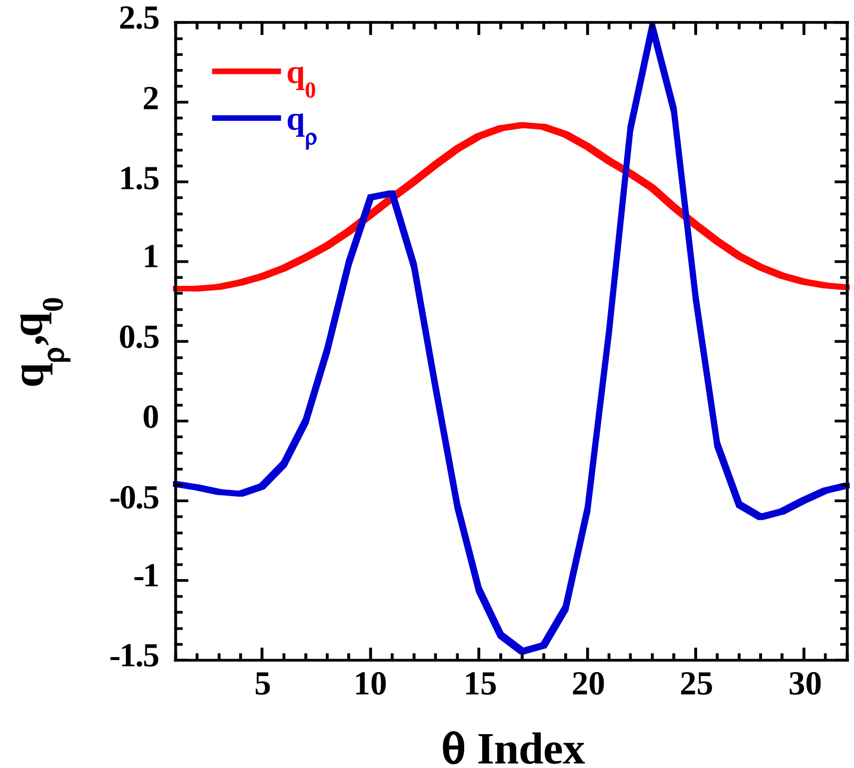




INTERFACE Code

- Output from INTERFACE =>Equilibrium θ-dependent tables for PG3EQ module





Summary and Future Directions

- Incorporation of realistic geometry in the Summit Framework through the PG3EQ module is proceeding

- Once completed, a relevant realistic geometry cross-check with GS2 is the next logical incremental step

- Investigation of global extension of the Summit Framework through the PG3EQ module is likely to follow: By extending the poloidal cross section to 2π, a complete toroidal annulus can, in principle, be simulated

Summit Gyrokinetic Team

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